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EXPERIMENTAL INVESTIGATION OF THE PHYSICAL PROPERTIES

OF MEDIUM AND HEAVY OILS, THEIR VAPORIZATION

AND USE IN EXPLOSION ENGINES

By Fritz Heinlein

PART I

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PART I.

Introduction

With the rapidly increasing use of motor cars and the ex-
tensive employment of explosion engines in agriculture, the
consumption of light oils has increased enormously and the
prices of these oils have continually risen. Efforts have ac-
cordingly not been lacking to increase the fuel-oil yield of
the coal abundantly available in Germany and especially to
transform the heavy oils obtained from the distillation of
coal and lignite into light fuel oils. Parallel with these
purely chemical processes, engine designers have sought by
constructive means to remove the difficulties which now inter-
fere with the use of heavy oils in explosion engines.

While little has yet been learned from chemistry concerning
profitable methods for obtaining an abundant supply of light
oils from coal and heavy oils, engine designers have already
made considerable progress toward the solution of the fuel
problem. This progress has been made in two fundamentally dif-
ferent directions, which may be briefly distinguished as fol-
lows:

1. The group of engines with medium and high-pressure car-
buretion in the cylinder;

.2. The group of engines with low-pressure carburetion of
the heavy oils before reaching the cylinder.

Carburetion does not here mean the complete transformation
of liquid fuels into the chemical condition of simple gaseous
hydrocarbons, but into as thorough a mixture as possible of
air and fuel, which, beginning with the atomization of the lat-
ter must, as a result of the partial evaporation of the atom-
ized fuel, be so far advanced, up to its ignition, as to pro-
duce a sootless combustion of the mixture.

In the first case, the solution is sought by the employ-
ment of auxiliary pumps for delivering and vaporizing the fuel
on its admission to the cylinder or by the use of hot-bulb en-
gines or their modifications. For this purpose a new structur-
al form of the engine is desirable. The recently perfected
method of solid injection has afforded a new incentive to ren-

der heavy oils available for motor-car engines.   A comprehen-
sive article on this subject by F. E. Bielefeld ("Schwerölmot-
oren für Fahrzeuge unter besondere Berücksichtigung ihrer Wirt-
schaftlichkeit." "Autotechnik" 1924, No. 17), gives a good idea
of the present status of this engine class and is further sup-
plemented by the recent publication of two articles by Profes-
sor A. Loschge on the Acro engine ("Der Acro-Motor," "Autotech-
nik" 1924, No. 26, and 1925, No. 3) and by R. C. Von Gorrison,
Hannover on a Dorner heavy-oil engine ("Der Schwerölmotorwagen
von Dorner," "A.D.A.C. Sportzeitung," No. 1, Jan. 6, 1925).
According to both these publications, we have come, in this
direction, very close to a solution of the heavy-oil problem
for automobile engines, if we have not already reached a defi-
nite utilizable solution.

Along with the development of these high-pressure and
medium-pressure heavy-oil engines, we have sought from the be-
ginning to adapt the low-pressure carburetor engine, which
works with suction intake and low compression up to about 5
atm. (5 kg/cm²) = 71 lb./sq.in.), to heavy fuels without chang-
ing their internal structure.   The entire work of producing
an ignitible mixture of heavy oil and air is left to the car-
buretor in this engine class, the same as in light-oil engines.
The carburetor alone has undergone many changes and seems to
be capable of perfect adaptation to the complicated loading
and operating conditions of automobile engines.   Hence nearly

all carburetor manufacturers have placed on the market carefully constructed heavy-oil carburetors (Dr. A. Heller, "Schwerölbetrieb bei Kraftwagen," "Zeitschrift des Vereines deutscher Ingenieure" 1923, No. 10; W. A. Ostwald, "Schwerölbetrieb mit Doppelgrätzin-Vergaser," "Autotechnik" 1923, No. 19) based on the carburetors with spraying nozzles almost universally used for light oils.

For a comprehensive solution of the problem of heavy-oil carburetion in low-pressure carburetor engines, there is still a lack of experiments on the physical properties of the heavy oils, which affect their vaporization, and a critical discussion of how far the vaporization can be carried and the atomization of the fuels must be carried, in order that the mixtures of air and heavy oils may attain the same degree of perfection as the light-oil mixtures and burn without freeing carbon.

We will therefore attempt in this article to define the technically important physical properties of the heavy oils, in so far as these properties affect the vaporization under the pressure and temperature conditions which exist during the intake phase of the engine. From the results of these experiments, conclusions will then be drawn (with mathematical treatment of the vaporization process of the oils) on the state of the vaporization, as it takes place under the conditions existing in the engine. By comparison with the light oils under like conditions, it is then obvious as to how far the atomiza-

tion of the heavy oils must be carried, in order to employ them successfully in carburetor engines.

In order to make the experiments more comprehensive, five heavy oils, two medium oils and two light oils were tested.

I. Heavy oils.

    a) Gas oil   (petroleum distillate),

    b) Rositzer oil   ("   "   ),

    c) Paraffin oil   (lignite   "   ),

    d) Coal-tar oil I   (coal   "   ),

    e) Coal-tar oil II ("   "   ).

II. Medium oils.   III. Light oils.

    a) Solar oil,   a) Gasoline,

    b) Kerosene   b) Benzol (benzene).

Both the light oils (gasoline and benzol) were included in the investigation, because they have hitherto been the principal fuels used in carburetor engines and because conclusions can be drawn from the properties of these fuels concerning the conditions required for the vaporization of even heavy oils for their successful use as engine fuels.

General statements concerning liquid fuels.- The liquid fuels, from the volatile gasoline to the heavy oils, are to be regarded as mixtures of saturated and unsaturated hydrocarbons. According to their source they belong, for the most part,

either to the aliphatic series or to the aromatic series of hydrocarbons, the latter occurring chiefly in the fuel oils derived from the distillation of coal. They differ fundamentally from the chemically homogeneous substances, such as alcohol and pure benzol (benzene) $C_6 H_6$, and their behavior, while being converted from the liquid to the gaseous state, is characterized by the phenomena of physical mixtures.

1. The liquid fuels show no uniform boiling point at first, but boil within certain prescribed limits.

2. In evaporating the fuels at constant external pressure, the lighter components evaporate first and the temperature continually rises. Consequently, the vapor tension decreases as the evaporation proceeds.

This behavior of the fuel oils involves an accurately determinable vapor pressure only when the liquid component with the lowest boiling point is still present in the liquid form in the Torricellian vacuum at the temperature of the experiment. With a spatial increase of the vacuum, it happens, however, that the light liquid components completely evaporate and occur above the heavy components as unsaturated vapors and consequently no longer show the maximum saturation pressure of the fuels at the same temperature. This fact must be taken into account in the determination of the vapor pressures and can not be disregarded in estimating the rate of evaporation.

Physical properties of liquid fuels.- The physical proper-
ties affecting the vaporization of liquid fuels are of prime
importance in judging the possibility of their utilization in
explosion engines. In addition to their chemical abalysis,
which is necessary for computing the quantity of air theoretic-
ally required, the following data must therefore be determined.

1. Specific gravities,

2. Boiling curves and limits,

3. Vapor pressures,

4. Specific volumes and vapor densities,

5. Vaporization heats,

6. Specific heats,

7. Vaporization rates and diffusion coefficients.

Chemical analysis.- The process does not differ from the
usual method and was carried out by me for all the fuels with
the electrical combustion furnace belonging to the inorganic
chemical laboratory of the Munich Technical High School.

The combustion tube was filled to two-thirds of its length
with copper oxide as the oxidizing agent. A boat-shaped plati-
num capsule, containing fine copper oxide in which a previously
weighed quantity of the oil was absorbed, was then introduced
into the empty end of the tube. Adjoining the platinum cap-
sule, a copper spiral was also introduced. In order to extract
any halogens which might be present, a silver spiral was intro-

duced into the opposite end of the tube. The tube was then
placed in the heating jacket of the electric furnace. The
platinum-boat end of the combustion tube was connected (with the
interposition of a drying apparatus) with an air-filled gaso-
meter. By turning the cock of a drying apparatus, connection
was made with a second gasometer, which was filled with oxygen.
All the connections had to be air-tight. A regulating cock was
introduced into the circuit before the drying apparatus, in or-
der to regulate the flow of the air or oxygen. The silver-
spiral end of the combustion tube was connected with a calcium
chloride tube and a potash apparatus, which were accurately
weighed before the experiment. The weight of the carbon diox-
ide was found in the potash apparatus and the weight of the
water in the calcium chloride tube and therefrom the amounts of
carbon and hydrogen contained in the fuel were calculated. It
was necessary to inclose gasoline or benzol in a small bulb of
thin glass, sealed by melting, and to place the bulb in a sepa-
rate tube which was introduced into the circuit before the com-
bustion tube. After the bursting of the bulb, the air stream
was saturated with the fuel vapors and carried them into the
combustion tube.

Three analyses were made with each fuel and the mean re-
sults are given in

TABLE I.

Fuel	Sp. grav. at 15°C(59°F)	Chemical analysis		Boiling limits at 720 mm (28.35 in.) Hg				Remarks
		% C	% H	from		to		
				°C	°F	°C	°F	
Gas oil	0.864	86.92	12.94	190	374	340	644	0.2% unevap.
Rositzer oil	0.907	84.30	11.05	140	284	325	617	4.1% "
Paraffine oil	0.906	86.94	12.91	200	392	370	698	1.1% "
Coal-tar oil I	0.910	87.50	12.01	90	194	225	437	1.3% "
Coal-tar oil II	0.852	86.98	12.62	120	248	300	572	1.1% "
Solar oil	0.850	86.30	13.40	155	311	275	527	All evap.
Kerosene	0.813	85.88	14.10	150	302	268	514	5% unevap.
Gasoline	0.739	85.70	14.30	60	140	120	248	All evap.
Benzol	0.870	91.35	8.30	75	167	160	320	" "

The specific gravities were determined with a specific-gravity bottle.

Quantity of air theoretically required for the combustion.- This can be determined from the chemical analysis of the fuel. The following computation accords with the combustion formulas.

$$2 \ H_2 + O_2 = 2 \ H_2O \qquad\qquad C_2 + 2 \ O_2 = 2C \ O_2$$

$$4 \ kg + 32 \ kg = 36 \ kg \qquad\qquad 24 \ kg + 64 \ kg = 88 \ kg$$
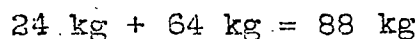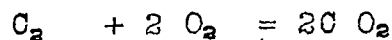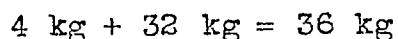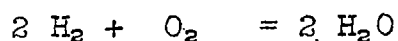
From these formulas we obtain, for coal-tar oil I, the volumetric proportions at 15°C (59°F) and 760 mm (29.92 in.) Hg as follows:

0.1201 kg H_2 + 0.744 m^3 O_2 = 1.488 m^3 H_2O.

0.8750 kg C + 1.806 m^3 O_2 = 1.806 m^3 CO_2.

0.9951 kg fuel + 2.550 m^3 O_2 = 1.488 m^3 H_2O + 1.806 m^3 CO_2.

or, on adding the weight (0.0049 kg) of the impurities (ashes, etc.) not included in the above:

1 kg fuel + 2.55 m^3 O_2 = 1.488 m^3 H_2O + 1.806 m^3 CO_2.

The theoretical combustion equation is accordingly

1 kg fuel + 12.14 m^3 air = 1.488 m^3 H_2O + 1.806 m^3 CO_2 + 9.59 m^3 N_2.

In determining the gas volumes, the mean barometer reading of 725 mm (28.54 in.) Hg during the experiments was taken, which gave the following values:

0.1201 kg H_2 + $\dfrac{22.4 \times 0.1201 \times 760 \times 288}{4 \times 725 \times 273}$ m^3 O_2 =

$2 \times \dfrac{22.4 \times 0.1201 \times 760 \times 288}{4 \times 725 \times 273}$ m^3 H_2O and

0.875 kg C + $2 \times \dfrac{22.4 \times 0.875 \times 760 \times 288}{24 \times 725 \times 273}$ m^3 O_2 =

$\dfrac{22.4 \times 0.875 \times 760 \times 288}{24 \times 725 \times 273}$ m^3 CO_2 or

0.1201 kg H_2 + 0.744 m^3 O_2 = 1.488 m^3 H_2O

0.875 kg C + 1.806 m^3 O_2 = 1.806 m^3 CO_2

The weight of the combustion water is

$w = \dfrac{1.488 \times 18}{22.4} = 1.195$ kg (2.635 lb.)

and the volumetric share of the CO_2 in the noncondensable portion of the combustion products is

$$\frac{1.806 \times 100}{1.806 + 9.59} = \frac{180.6}{11.396} = 15.87\%$$

In the cylinder combustion of heavy-oil fuel mixtures, according to previous experiments, a greater excess of air is necessary for complete combustion. Conclusions may be reached regarding the lack or excess of air in the cylinder from the above computation of the theoretical air requirement and from the determination of the volumetric content of CO_2 and of unburned CO and O in the exhaust gases of an engine.

Table II gives the theoretical air consumption, the weight of the combustion water and the percentage of CO_2 in the total volume of the combustion products for the theoretically required amount of air.

TABLE II.

Fuel	Chemical analysis		Theoretical consumption of air	
	% C	% H	kg	lb.
Gas oil	86.92	12.94	12.36	27.25
Rositzer oil	84.3	11.05	11.85	26.12
Paraffine oil	86.94	12.91	12.37	27.27
Coal-tar oil I	87.5	12.01	12.14	26.76
Coal-tar oil II	86.98	12.62	12.25	27.01
Solar oil	86.3	13.40	12.42	27.38
Kerosene	85.88	14.10	12.60	27.78
Gasoline	85.70	14.30	12.63	27.84
Benzol	91.35	8.30	12.30	27.12

TABLE II (Cont.)

Fuel	Combustion with theoretical quantity of air						% CO_2 in the noncondensable portion.
	Wt. of combustion water		Vol. of CO_2		Vol. of N_2		
	kg	lb.	m³	cu.ft.	m³	cu.ft.	
Gas oil	1.287	2.837	1.602	56.57	9.76	344.67	14.09
Rositzer oil	1.099	2.423	1.748	61.73	9.14	322.77	16.05
Paraffine oil	1.283	2.829	1.800	63.57	9.77	345.02	15.55
Coal-tar oil I	1.196	2.637	1.806	63.78	9.59	338.67	15.85
Coal-tar oil II	1.256	2.769	1.790	63.21	9.67	341.49	15.62
Solar oil	1.331	2.934	1.780	62.86	9.80	346.08	15.35
Kerosene	1.403	3.093	1.772	62.58	9.95	351.38	15.11
Gasoline	1.421	3.133	1.770	62.51	9.97	352.09	15.08
Benzol	0.828	1.825	2.030	71.69	9.72	343.26	17.28

Evaporation curves.- These show the evaporated quantities of
fuel as plotted against the boiling temperatures and are plotted
by taking the evaporated volumes in % of the original volume as
the ordinates and the corresponding temperatures of the oil vapor
as the abscissas.

Hence 100 cm³ (6.1 cu.in.) of each fuel was evaporated in
the apparatus made by Runge of Berlin for the Berlin "Physikalisch-
Technischen Reichs-Anstalt" and the distillates were collected in
graduated vessels. The evaporated volumetric percentages were
obtained directly from the quantities of the distillates collected
at the different temperatures.

The curves in Fig. 1, for all the fuels tested, show that the medium and heavy fuels do not evaporate at atmospheric pressure within so narrow temperature limits and so uniformly as gasoline and benzol. Furthermore, they leave, within the given boiling limits, residues which are decomposed only at the high combustion temperatures in the engine cylinder. The evaporation temperatures are moreover considerably higher than for the light oils.

Vapor tensions.- The vapor tension of a liquid at a given temperature depends, in chemically homogeneous substances, only on this temperature and rises and falls with it. The vapor-tension curve, which represents this dependence of the vapor pressures on the temperatures is, at the same time, the limiting curve between the wet and superheated vapor. It is definitely determined only when the liquid has a constant boiling temperature at the existing external pressure and does not change as the evaporation proceeds. From the vapor-tension curve there can be found directly the temperature at which the complete evaporation of a given quantity of liquid (to a predetermined volume) is possible. In this connection, however, the saturation pressure must be determined as a partial pressure in the given volume of vapor and air for the evaporation. The greater the air space is, in which the evaporation takes place, just so much smaller will be the partial pressure of the liquid and just so much lower the temperature at which complete evaporation is possible.

The vapor tensions cannot be so readily determined in liquid mixtures as in chemically homogeneous substances. The process of evaporation has already been briefly described under the heading "General statements concerning liquid fuels" and will be more fully discussed before we proceed to the determination of the vapor-pressure curves.

In the isothermal evaporation of the fuel in a Torrecellian vacuum, we will observe that the fuel continues to evaporate until equilibrium is established between the fuel liquid and the fuel vapor. The latter contains lighter hydrocarbons than the former, because the lighter components of the fuel evaporate at a lower temperature than the heavier. At a given temperature we will obtain a physically correct vapor pressure, which is composed of the pressures of all the liquid components, when the lightest liquid component is present in the vacuum in both the vapor and liquid form. As soon as the lighter liquid components are no longer present in the liquid form, they cease to appear at their full saturation pressures in the total pressure of the fuel. The vapor pressure is then smaller than the true saturation pressure of the fuel. This phenomenon was thoroughly investigated in a preliminary experiment with the apparatus for determining the vapor pressure which will be described later. An increase in the size of the vacuum, due to the sinking of the mercury and of the liquid fuel, resulted in a further evaporation of the fuel at constant temperature, but simultaneously also in lowering the

vapor pressure. It was only with a vacuum of less than 15 cm³
(0.915 cu.in.) for the heavy and medium oils and 20 cm (1.22
cu.in.) for both the light oils, that a constant vapor pressure
at constant temperature was observed, up to temperatures of re-
spectively 60 and 30°C (140 and 86°F), for the 0.1 gram of fuel
used.

In order to be able to establish, however, the vapor ten-
sions in a practical manner for the future consideration of the
evaporation process, I refrained from determining the absolute
values of the vapor tensions at the small volumes of 15-20 cm
(0.915-1.22 cu.in.) which never occur in the engine cylinders.
These values would have been much too high for the actual evapora-
tion process at the given volume in the engine. In all the vapor-
pressure experiments, I have therefore determined the vapor vol-
umes corresponding to the vapor pressures for the temporarily
constant temperature; established this dependence in pressure-
volume curves for every temperature; and plotted therefrom the
vapor-pressure curves for predetermined volumes, whereby the ob-
served vapor volumes were converted to 0.1 gram fuel. This made
it possible to calculate the vapor pressures under like condi-
tions for all the fuel oils.

The vapor-pressure curves for each fuel form a group corre-
sponding to the dependence of the vapor pressures on the volume.
The experimental results are given in Tables III – XI and Figs.
3a – 11b, (Part II, Technical Memorandum No. 363).

The vapor tensions for liquid fuels had often been previously determined without taking account, however, of the above-described phenomenon. On the vapor tensions of heavy oils we have Neumann's experiments (K. Neumann, "Untersuchung an der Dieselmaschine," "Zeitschrift des Vereines deutscher Ingenieure" 1918, p. 706), which were performed, however, at constant volume and served as a basis for the discussion of evaporation in constant-pressure oil engines.

Experimental procedure and apparatus.- The experiments were performed according to the isothermal method, which is the best for liquid mixtures. Static and dynamic methods give accurate results only with chemically homogeneous substances. The apparatus used in the experiments (Fig. 2) was made of changeable length and can be used both to determine the vapor pressures and the vapor densities at constant pressure.

A seamless thick-walled steel tube d, of 6 mm (2.36 in.) inside diameter, with three welded steel-tube connections, is fastened with iron straps to an iron pan and a small table which supports the whole apparatus. Welded to each tubular connection there is a threaded piece for receiving a packing box, into which is inserted a glass tube well tightened with rubber gaskets: 1. experiment tube a, provided with a cubic-centimeter scale; 2. barometer tube b; 3. pressure-gauge c, which is needed for experiments above atmospheric pressure. A thin bent steel tube is welded to the tube d which joins the three glass tubes. The

bent tube is connected with a glass tube   g,   about 700 mm (27.6 in.) long, the latter being connected with the rubber tube   e, and the glass mercury reservoir   R.   The glass tube   g   carries a tightly-fitted cock   h.   The mercury reservoir   R   is a cylindrical glass receptacle with a calcium chloride tube at the top and a thick nipple for connecting with the tube   e.   The reservoir rests in a felt-lined oak sheath which can be raised or lowered on a sheet-steel guide.   The arresting device is a steel spring, which is screwed to the oak sheath and engages in the notches in the steel guide.   The latter is screwed to an oak support, which has a wood base and carries a wooden measuring stick with a millimeter scale.   On the measuring stick there is a steel slide with a spring stop.   This slide carries a glass tube   f,   for reading the levels of the three tubes   a, b, and c.

Since the room was too small for reading the mercury meniscus with a telescope, the tube   f,   had to be resorted to. This was secured to the slide by iron straps and branched toward the experiment tubes in two arms and terminated in front of the measuring stick in a vertical tube about 6 cm (2.36 in.) high.   Likewise, at the distances of the observation tubes   a, b, and c   on both arms of the glass-tube fork before and behind the observation tubes there are 6 mm vertical tubes, all communicating with one another and, of course, also with the vertical tube in front of the measuring stick.

If this glass fork is filled with a liquid, preferably

Xylol on account of its concave meniscus, and the meniscus of
the fork is made to coincide with the meniscus of each observa-
tion tube, we obtain the desired reading on the measuring stick.
Since all the readings are made on the same scale, which under-
goes no expansion, there are no reading errors to be corrected.

The tube c serves to determine the level of the lower
mercury surface, which is below atmospheric pressure. The cock
h provides an airtight shut-off for tube c during the experi-
ment. The upper glass tube with the mercury seal comes into use
only at high vapor pressures. It was not needed in these exper-
iments. The glass tube b serves as an ordinary barometer and
has, at the top, a perfectly fitted glass stopper with mercury
seal. A thermometer gives the temperature of the barometer
tube, which is affected by the higher experiment temperature in
the tube a and necessitates a correction of the barometer
column. The experiment tube a has an inside diameter of
16 mm (0.63 in.) and is provided with a cubic-centimeter scale
for reading the vapor volumes.

After the vapor tensions are determined at the different
temperatures, provision is made for the experiment tube a to
be heated in each experiment by hot vapors of uniform tempera-
ture. For this purpose, tube a is surrounded with a glass
cylinder, which is closed at the bottom by the cork p. In or-
der to prevent the bursting of the glass jacket at high tempera-
tures, the cork is surrounded by a glass ring containing, in the

space thus formed, about 1 cm (0.4 in.) of mercury q,   thus
forming a perfect seal and preventing all tension in the glass
cylinder.   Two glass tubes k and l pass through the cork and
terminate above the mercury in the heating jacket.   Tube l in-
troduces the heating vapors and extends about 5 cm (2 in.) into
the heating jacket, while tube k returns the liquid from the
condensed vapors to the heating flask.   For convenient demount-
ing, each of these tubes is in two parts with rubber connec-
tions capable of withstanding temperatures up to $200^{\circ}C(392^{\circ}F)$.

The heating is accomplished indirectly by means of electric-
ity on account of the fire danger.   A copper flask containing
the heating liquid stands in an electrically heated vessel
filled with rape oil and is closed with a three-hole cork.   The
tube k reaches to the bottom of the flask; the tube l ,   only
into the vapor space at the top.   A third glass tube m,   reach-
ing to the bottom of the flask, returns the condensed vapors
to the flask.   The heating vapors pass from the flask through
the tube l into the heating jacket, from which they pass, .
through the upper cork, to a return cooler connected with the
water pipe, unless they condense before reaching the cooler.
The glass tube m returns the condensed liquid to the copper
flask.   The circuit of the heating vapors is therefore a closed
one and the loss of heating liquid is small.   The apparatus is
assembled by rubber connections, so that it can be readily
taken apart and put together again.

The regulation of the electric heating is readily accomplished by switched-in resistances, so that the vapor production proceeds very uniformly. The temperature of the heating vapors is taken in the heating jacket by a thermometer calibrated at the "Phys.-Techn. Reichsanstalt" in Berlin. The thermometer is suspended on a wire, so that it can be easily raised and lowered from without.

The following chemically pure substances, with constant boiling points, were employed as heating liquids:

Substance	Boiling point	
	^{o}C	^{o}F
Ether	34	93.2
Carbon disulphide	44	111.2
Methyl alcohol	63	145.4
Benzol (benzene)	78	172.4
Water	100	212.0
Amyl alcohol	130	266.0
Turpentine	160	320.0
Aniline	178	352.4

The boiling points changed somewhat during the course of the experiments, partly due to changes in the barometric pressure and partly due to residues of the heating liquid last used. This circumstance did not affect the results, however, because the temperature of the heating vapors was known.

Preparation and assembling of the apparatus.- Before insert-
ing the three glass tubes, a, b, and c, the apparatus was care-
fully dried by drawing through it for about 30 minutes, air
which had been previously dried by calcium chloride. Mercury
that had been well boiled and then cooled in a dessicator was
now poured into the mercury reservoir until it rose above the
three packing boxes. By lowering the mercury reservoir, the
apparatus could be entirely filled, without too much mercury
rising above the packing boxes. The mercury reservoir was then
closed with a rubber stopper, into which a calcium chloride tube
was inserted, so that no moisture could enter. The tubes were
then inserted, after having been previously heated to expel
any moisture adhering to their walls. The level of the mercury
in the reservoir R could be verified by comparison with the
standard barometer in the physical laboratory. The large cork
for the lower mercury seal was then put in place; the glass
tubes were inserted in the packing boxes; the latter were tight-
ened; and the apparatus was closed. Raising and lowering the
mercury reservoir several times showed whether there were any
air bubbles left in the connecting tube as far as the glass
tubes a and b. In case there were, they could be allowed to
escape by opening the glass stoppers at the tops of the tubes
a and b. After this preliminary testing of the apparatus, the
cock i was closed with the mercury reservoir raised and the
mercury seals were produced for the tubes a and b.

After these preparations, the oil to be tested could be introduced into the experiment tube a.   For this purpose a thinly blown glass bulb, ending in a capillary tube about 1 cm (0.4 in.) long, was used. After the bulb was weighed empty, it was warmed slightly and immersed in the oil, which was drawn into it as a result of the cooling. By repeating this process several times, the bulb and capillary were entirely filled. The weight of the oil was then found by weighing the filled bulb and deducting the weight of the empty bulb. The mercury reservoir was then raised so high that on removing the stopper at the top, the mercury flowed into the widened part of tube a. . The filled bulb, together with the stopper, could then be easily pressed into the tube.

After making sure that the stopper was tight and that the mercury seal was all right, the mercury reservoir was lowered, thereby producing the vacuum in which the evaporation immediately began. The capillary tube was left open so that the evaporation did not depend on the bursting of the bulb. The evaporation proceeded smoothly in the vacuum without disturbance or delay. After the liquid had been introduced into the tube, the heating jacket was put in place, the mercury seal was produced at the bottom, the cork was inserted at the top and the connections were made with the heating flask and the return cooler.

In beginning the experiments, readings of the mercury level were taken at the room temperature for the different posi-

tions of the mercury receptacle. The experiment was then begun
with ether for the heating liquid and with a delay of about 30
minutes before each reading, for the whole heating jacket to be-
come evenly heated and until it could be assumed that the exper-
imental fluid in the vacuum had acquired the same temperature.
Before each experiment the barometer stand in the apparatus
was found by reading the lower mercury level (which communicat-
ed with the mercury reservoir) on the tube c with the cock i
open and also the position of the mercury in the barometer tube
b at the top. The difference between the level of the mercury
in the barometer tube and in the experiment tube gave the vapor
pressure at the temperature of the heating jacket. Since this
vapor pressure did not remain constant on lowering the mercury
reservoir, even though liquid fuel were still present in the
vacuum (which, according to the explanation already given,
could not be expected to be otherwise), the vapor volumes had
to be read on the experiment tube simultaneously with the
vapor pressures. The following readings were accordingly made:

a) For the vapor-pressure determinations:

1) Mercury level in barometer b,

2)   "   "   " experiment tube a,

3) Vapor volume (cm³) in tube a,

4) Temperature in heating jacket,

5)   "   " barometer tube,

6)   "   of room,

7) Barometer.

b) For the vapor-density determination:

1) Vapor volume (cm^3), after all the liquid was evapor-
    ated,

2) Weight G of the evaporated fuel.

Translation by Dwight M. Miner,
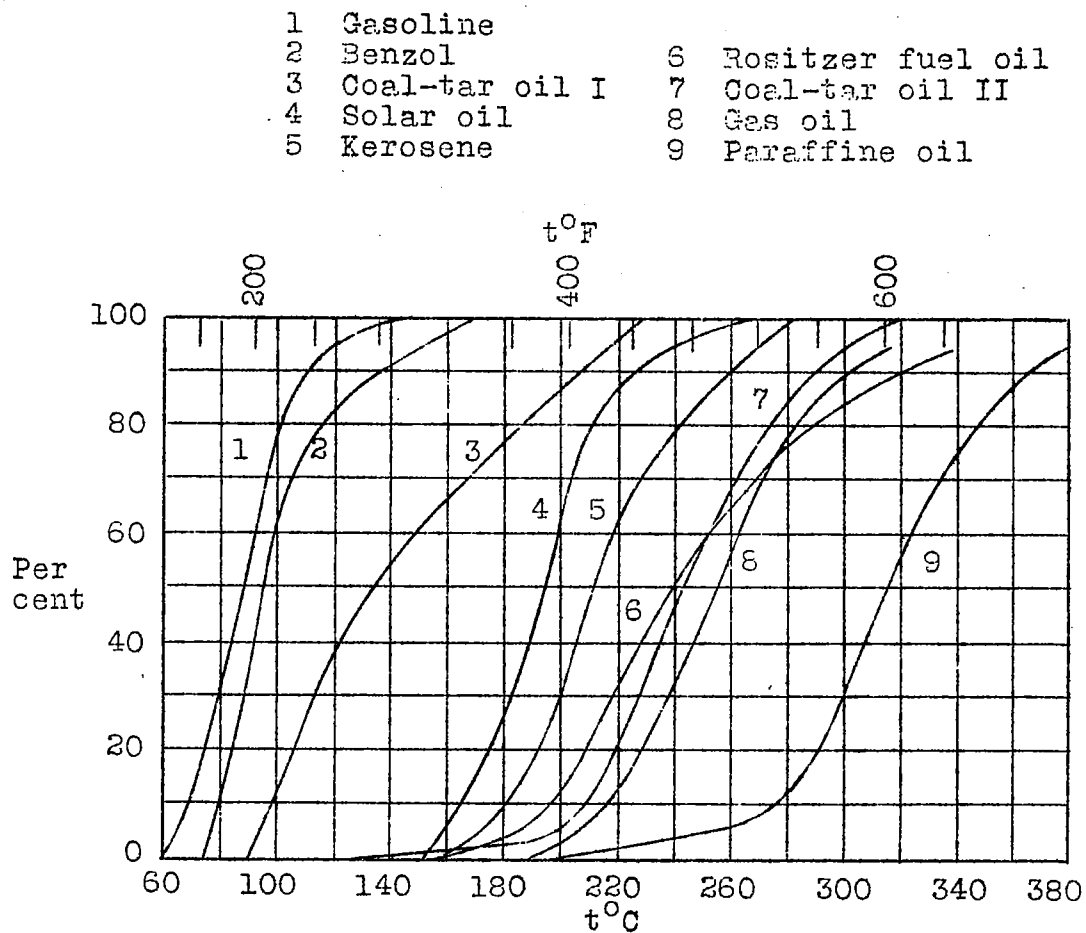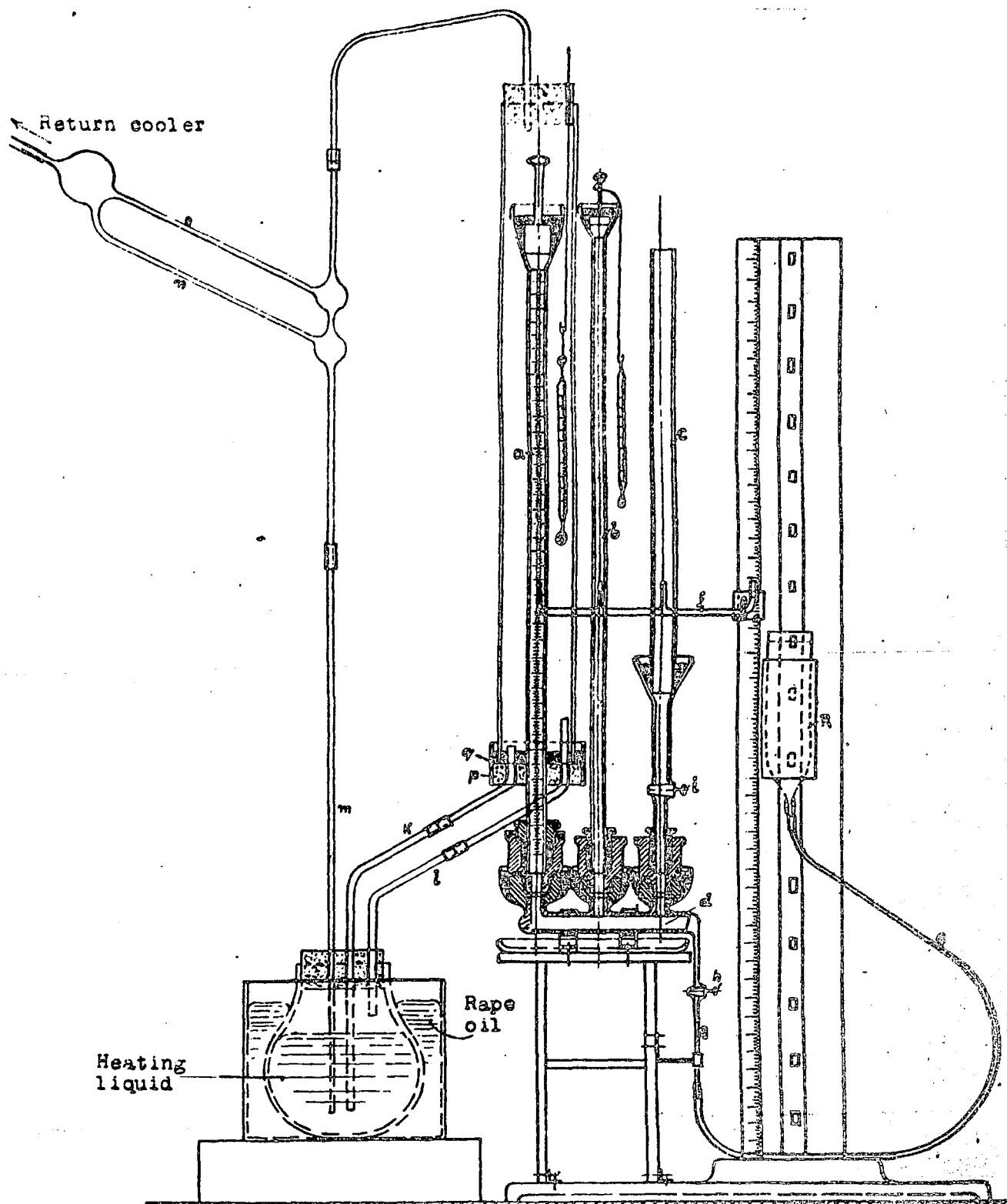National Advisory Committee
for Aeronautics.

1　Gasoline
2　Benzol　　　　　　6　Rositzer fuel oil
3　Coal-tar oil I　　7　Coal-tar oil II
4　Solar oil　　　　8　Gas oil
5　Kerosene　　　　　9　Paraffine oil

Fig.1　Evaporation curves.

Fig.2   Apparatus for determining vapor pressure and vapor density